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(56) Documents Cited
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(54) **Position measurement apparatus**

(57) A precision measurement apparatus detects the point at which a measurement probe contacts the surface of an object 37 to be measured by detecting the formation of a magnetic circuit as the probe approaches the object. This is achieved by making the probe of an electroconductive material and locating the probe and the object (which must also be metal or similar electroconductive material) as part of a magnetic circuit. The circuit includes an inductive sensor 1 responsive to ambient or externally induced electromagnetic fields and which produces an output signal which changes in response to the circuit being formed. Because the circuit is formed before actual contact is made the apparatus can sense when the probe approaches the object and adjust its speed accordingly. In a preferred arrangement the probe may in fact be the cutting tool 36 of a CNC machine tool, in which case the apparatus may also be used to detect breakage of the cutting tool.

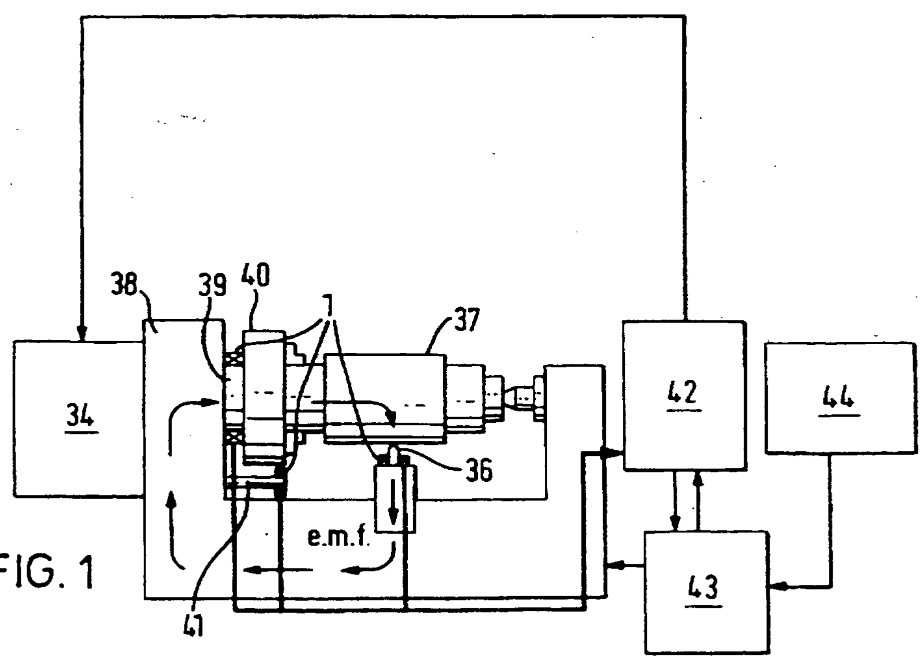

FIG. 1

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

This print takes account of replacement documents submitted after the date of filing to enable the application to comply with the formal requirements of the Patents Rules 1995

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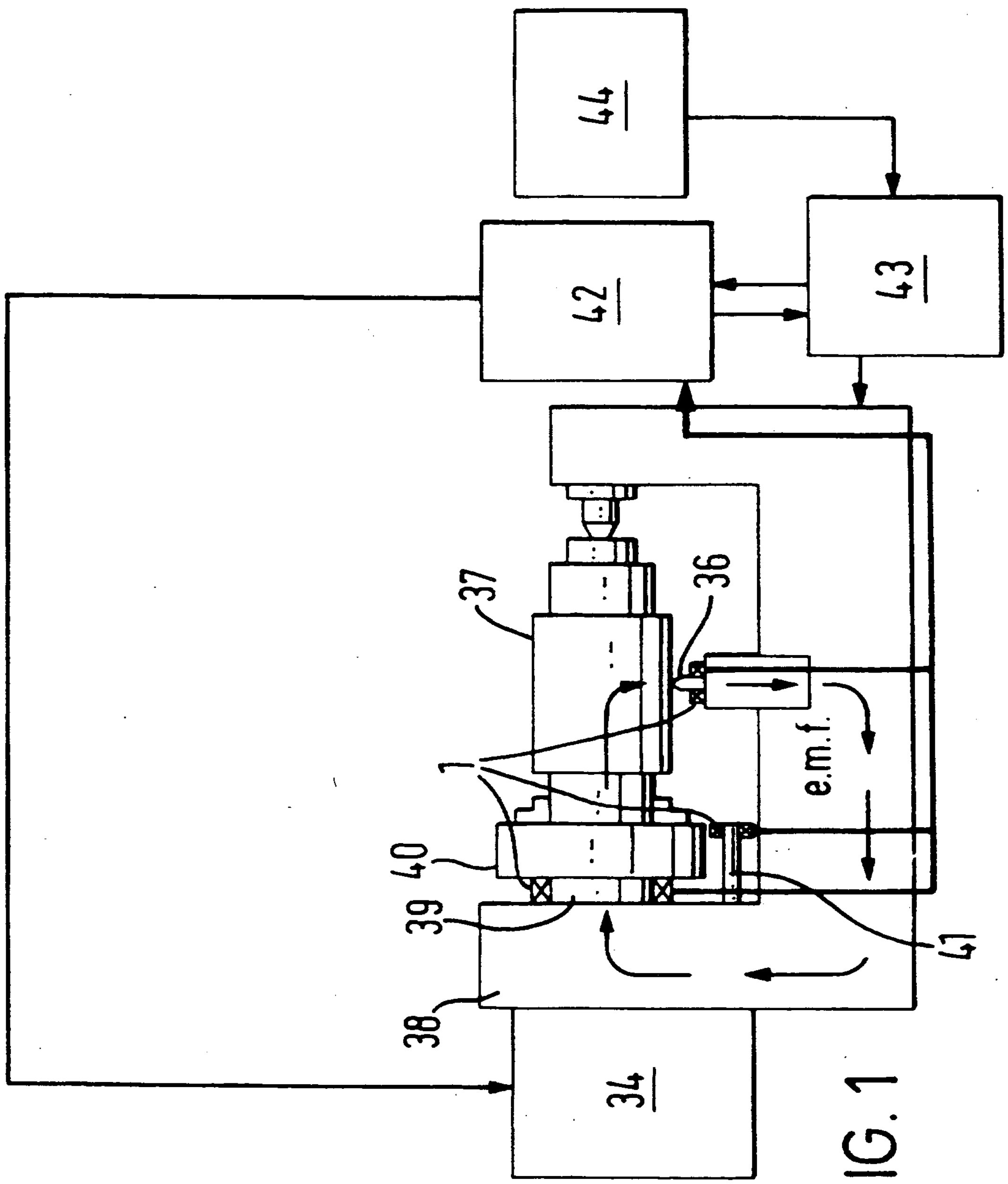


FIG. 1

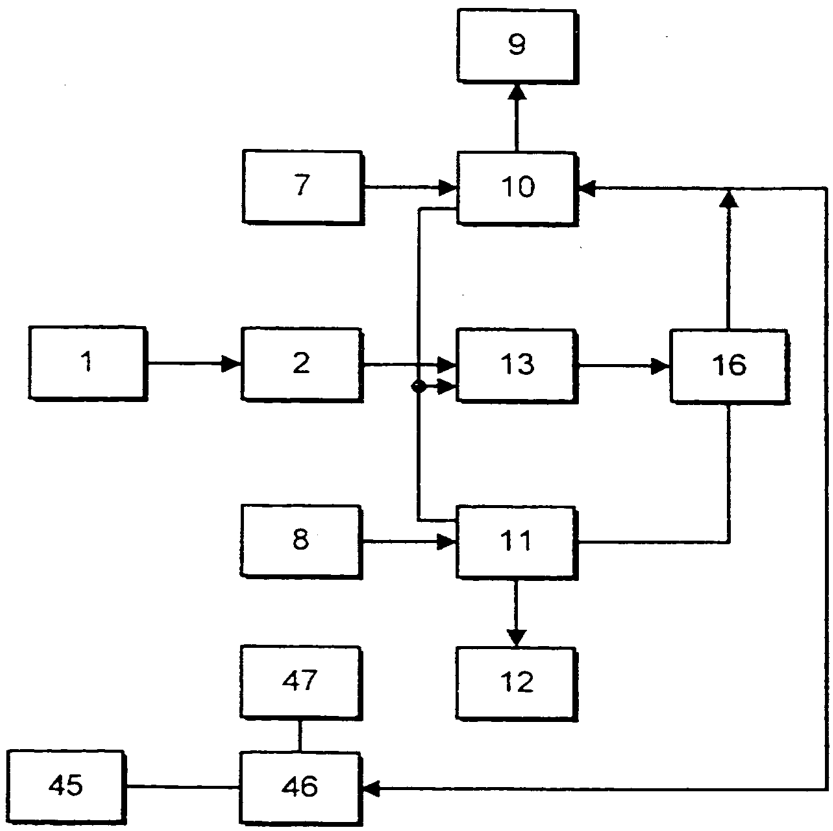


FIG. 2

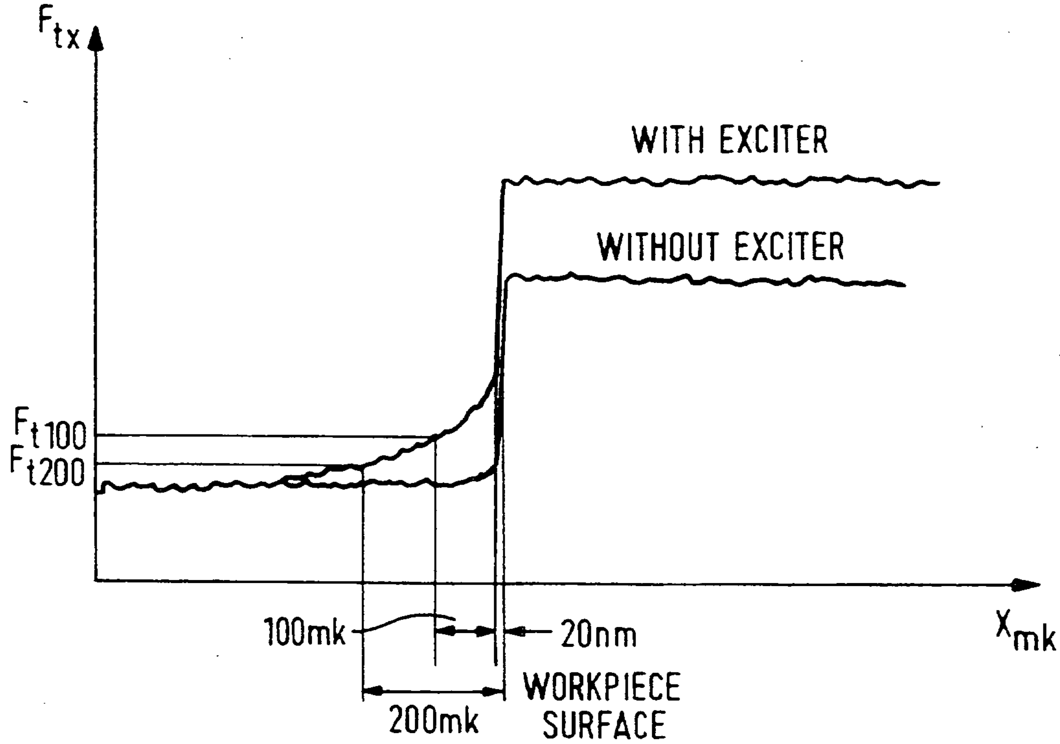
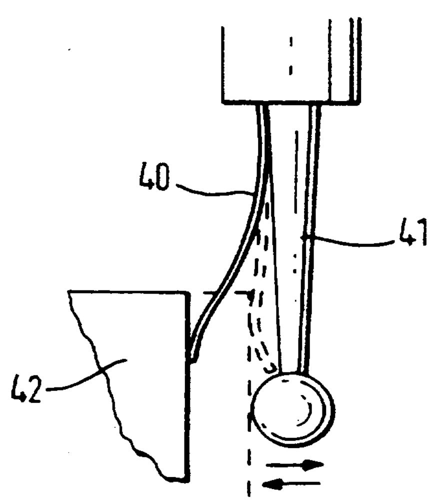

F_{tx}
WITH EXCITER
WITHOUT EXCITER
F_{t100}
F_{t200}
100mk
20nm
X_{mk}
200mk
WORKPIECE
SURFACE

FIG. 3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41
42

FIG. 4

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A POSITION MEASUREMENT APPARATUS

This invention relates to a position measurement apparatus, and in particular to such an apparatus that can simply but very precisely measure the position of a point on the surface of an object such as a workpiece.

High-precision (eg to within sub-microns) position measurement apparatus are used extensively in the manufacturing industry for object geometry measurements using co-ordinate measurement machines (CMM) and CNC machine tools and the quality of the finished product is closely related to the accuracy of such measurement apparatus. A number of such machines have been designed but generally they all work along similar principles. A touch probe or stylus is provided and the machine detects - in a number of differing ways - the point at which the stylus contacts the surface of the object being measured. The probe may be moved in the X,Y and Z directions in a controlled manner, usually under computer control, so that the co-ordinates in space of the probe may be known to a high degree of accuracy.

For example, US 5208993 discloses a touch probe having a complex precision biasing mechanism including a helical spring system and a movable shuttle. Upon contact of the probe on the object movement against this bias is detected. In US 5247751 a vibrating touch probe is provided with a piezoelectric element at its end remote from the contact point and a change in the piezoelectric effect is used to detect physical contact of the probe with the surface.

These prior systems have a number of disadvantages. Most notably they provide no indication of how close the probe or stylus is to the surface to be measured until actual contact is made - the system receives the same information from the probe whether it is a large distance away or just about to contact the surface. Such an arrangement means that an operator of the apparatus must be highly skilled since there is a danger that otherwise the probe may be brought into contact with the surface at too high a speed, with the potential of causing damage to the probe which is often of a vulnerable construction. Alternatively the apparatus may include a flexible reset probe design, but this is at the expense of accuracy

A further disadvantage is that the probe and the measurement apparatus is a separate element that must be brought to a workpiece whenever a measurement is to

be made. It is not easy to incorporate the prior measurement apparatus into a machine tool. Thus, for example, if measurements are to be made to check the dimensions of a workpiece being operated on by a machine tool the process is time consuming since the apparatus must be brought to the workpiece for the measurement to be made and then removed again afterwards.

According to the present invention there is provided a precision measurement apparatus for measuring a point on the surface of an electro-conductive object comprising, a measurement probe, means for moving said probe away from and towards an object to be measured and for detecting the position of said probe, said probe and said object to be measured being arranged in use such that a magnetic circuit is formed when said probe is in contact with or closely adjacent to said object, and an inductive sensor arranged to detect when said circuit is formed.

By means of this arrangement the apparatus is able to detect when the probe is very close - but not yet contacting - the surface of the object to be measured since the inductive sensor will detect the change in magnetic field created by the formation of the magnetic circuit which happens before actual physical contact is made. In cases where physical contact is to be avoided this proximity may possibly be used as the measurement itself, though it would not be very accurate and greater accuracy will of course be obtained normally by allowing the probe to contact the surface, which may in preferred embodiments be confirmed by the completion of an electrical circuit.

The inductive sensor simply comprises a wire coil around a ferrite core and which produces an output signal dependant on the strength of the magnetic field the sensor experiences. The sensor is exposed to ambient environmental fields (eg from radios, television sets, other items of machinery) and/or fields generated by an exciter. When the probe is close enough to the object to be measured for the magnetic circuit to be formed, the magnetic field experienced by the sensor changes and this change produces a change in the sensor output which may be detected. The detection of this change is relatively simple because it is not necessary to detect absolute values of the magnetic field experienced by the sensor. It is only necessary to detect the change caused by formation of the magnetic circuit, which change will be much greater than the random modulations occurring in the ambient electromagnetic fields.

Generally the ambient magnetic field is sufficient, however greater accuracy

still may be obtained by using an electromagnetic field exciter. The sensor is preferably located in the magnetic field - for example it may surround the contact probe or a spindle on which the object to be measured is mounted - but it may also be simply located nearby or be simply located around any convenient part of the magnetic circuit.

In a particularly preferred arrangement means may be provided for controlling the speed of movement of the probe towards the object to be measured as a function of the proximity of the probe to the object. Preferably the output of the sensor is input to processing means, and more preferably still this processing means may be used to control the speed of the probe. For example, the processing means may include a first channel of high sensitivity for determining a change in the sensor output indicative of the probe approaching the surface of the object, and a second channel for determining contact between the probe and the object. The probe may then be caused to move towards the object at a slower speed upon an output from the first channel detecting the approach of the probe to the object. Upon detection of contact the probe will be caused to stop moving, and the position of the probe will be stored in a memory and the probe may then be caused to retract from the object.

The measurement probe may be a separate element, however a particular advantage of the present invention is that it allows for the possibility of the measurement apparatus being integrated into a machine tool. For example the measuring probe may be the cutting tool of a cutting machine and the sensor may be provided either surrounding the cutting tool or surrounding the spindle on which the workpiece is mounted. This arrangement has many advantages over conventional arrangements in which a separate measuring probe must be provided. The cutting tool may be used to make measurements of the dimensions of the workpiece without the need to interrupt the cutting operation and bring to the workpiece a separate probe. This makes the measurement much faster and simpler and the results of the measurement may be fed directly back to the cutting tool control means to provide a form of feedback. Similarly the cutting tool may be used to ascertain the surface quality (eg roughness) of the workpiece.

An additional advantage is that the measurement apparatus may indirectly provide a means for detecting the condition of the cutting tool. For example if the

tool were to break or wear out this would result in a change of the magnetic field experienced by the sensor and which could be indicated to the machine operator.

Viewed from a further aspect the invention also extends to a method for measuring the position of a point on the surface of an object made of electro-conductive material comprising, moving a measurement probe towards an object to be measured, and detecting the position of the probe at which a magnetic circuit is formed when the probe is in contact with or closely adjacent to said object.

Some embodiments of the invention will now be described by way of example and with reference to the accompanying drawings, in which:-

Fig.1 is a schematic view of a position measurement apparatus incorporated into a machine tool,

Fig.2 is a block diagram showing the processing of the sensor output signal,

Fig.3 is a plot showing a typical sensor output signal as the measuring probe/cutting tool approaches and contacts a workpiece, and

Fig.4 is a view of a modification of the embodiment of Figs. 1 to 3.

Referring firstly to Fig.1 there is shown a CNC machine tool comprising a rotatably driven spindle 39 on which a workpiece 37 may be mounted, and a cutting tool 36 which is under the control of CNC controller 43 so that the position of the cutting tool 36 is always known. The tool is movable according to CAD/CAM system 44 data in three mutually orthogonal directions (X,Y,Z) under computer control so that the co-ordinates of the tool with respect to a reference frame may always be known. An inductive sensor 1 is provided in one of a number of possible locations. The sensor 1 comprises a wire coil around a ferrite core and Fig.1 shows three possible locations: surrounding the cutting tool 36, surrounding the spindle 39 between the machine tool frame 38 and a clamping fixture 40, and surrounding a set up attachment 41. It will be appreciated however that other positions may also be envisioned, and indeed more than one sensor could be employed. The sensor 1 provides an output to contact detection means 42 which will be described in greater detail further below.

In operation of this apparatus, as the cutting tool 36 is advanced towards the workpiece 37 and becomes very close to the workpiece a magnetic circuit is formed between the cutting tool, workpiece, spindle, and machine tool frame as shown by the

arrows in Fig.1. the formation of this circuit decreases the magnetic reluctance of the circuit and increases the magnetic flux passing through the sensor 1 producing a change in the sensor output.

Fig.3 illustrates the sensor output as the cutting tool approaches and then contacts the workpiece. When the cutting tool is at a distance from the workpiece the output signal Fn(x) is simply indicative of the noise of the ambient environmental magnetic fields. There is some minor modulation of the noise signal but otherwise it is generally constant. However as the cutting tool approaches to within 20nm of the workpiece the magnetic circuit starts to form and since the magnetic flux is concentrated within the circuit the sensor output Fap(x) increases. As will be explained in more detail below this increase - which is pre-physical contact - can be detected and the proximity of the cutting tool to the workpiece can be sensed. Finally, as the cutting tool contacts the workpiece surface the magnetic circuit is completely formed and the sensor output reaches its maximum value Ft(x).

Generally the ambient magnetic field will be sufficient for the sensor to produce a sufficiently large output signal and for the change in that signal upon approach and contact to be detected. However if necessary a magnetic field exciter 53 may be provided to generate a magnetic field. One effect of a greater external magnetic field from such an exciter is that the tool/workpiece separation at which a change in the sensor output may be detected can be increased, thus giving earlier warning of the approach of the tool to the workpiece. In a CNC operation the cutting tool may then be automatically slowed in its approach to the workpiece surface.

Fig.2 illustrates how the output signal from the sensor 1 is processed. The signal is passed to two identical channels: a contact approach channel and a contact detection channel through pre-amplifier 2 and buffer 3. Then the signal is sent to respective buffers 6 and 18 through signal refiners 5 and 17 in each channel. Buffer 6 amplifies the signal by a factor 10x greater than buffer 18 in order to provide the contact approach channel with greater sensitivity than the contact detection channel so as to determine the earliest tool approach.

The thus amplified signals are passed to comparators 13,25 which compare the signals with adjusted reference voltages taken from the high voltage supplies 7,19 through enables 10,22 to create a high comparator reference level. A lower

comparator reference level needed for robust signal registrations are created with adjusted reference voltages taken from low voltage supplies 8,20 through enables 11,23 closed at the beginning. If a comparator reference level is higher than its input signal the comparator output is a "logical 0" signal, otherwise a comparator output is a "logical 1" signal.

The enables 10, 11, 22 and 23 also activate optoisolators 9, 12, 21 and 24 that indicate output signals of contact approach or contact determination to the CNC machine. The comparators 13, 25 send signals to AND gates 14, 26 and to decimal counters 15, 27 that count the impulse number n repeatedly loaded by counter 32. The impulse number n is calibrated experimentally and has a maximum value for signal recognition from the noise. Counters 15, 25 send signals to AND gates 14, 26 if pulse number n calculation creates a clock cycle shorter than the duration time of the comparator "logical 1" signal. In the opposite case counters 15, 25 are reset by the comparator "logical 0" signal as well as counters 31, 32 through OR get 29.

If contact is approached or detected AND gates 14, 26 get comparator "logical 0" signals and counters signal simultaneously. In this case the signals from AND gates 14, 26 are sent to triggers 16, 28 which switch on low voltage supplies 8, 29 through enables 11, 23 and to switch off high voltage supplies 7, 19 through enables 10, 22. Triggers 16, 28 are reset by a signal from decoder 30 which in turn receives a signal from the pulse generator 33 through counters 32, 31.

In some circumstances contact between the cutting tool and the workpiece may be interrupted, for example if the workpiece surface is interrupted (eg by being provided with slots), or if a multi-edge cutting tool is used. For example, a multi-edge cutting tool may have from 2 to 20 edges and each edge will have a short contact time depending on various factors, including the number and disposition of cutting edges and the speed of rotation. Such interruptions should not prevent the measurement apparatus and to achieve this aim the system response time needs to be set to be greater than the contact interrupt time. For example, when the cutting edges are further apart or the cutting tool rotation speed is reduced, the response time must be increased and vice versa.This is achieved by the CNC machine being programmed to provide different system response times in conjunction with decoder 30 in accordance with different possible sets of conditions.

The output system signals to the CNC serve to reduce cutting tool approaching speed or to stop further advance of the cutting tool, to memorize the co-ordinates and to start retraction of the cutting tool. As this retraction breaks the tool/workpiece contact in both channels triggers 16, 28 switch enables 10, 22 on and enables 11, 23 off so that the system is ready to begin a new cycle.

In order to increase the accuracy and reliability of the system the pulse generator 33 activates an electromagnetic field exciter 34 to create an alternating electromagnetic field with a frequency corresponding to the system frequency and recognisable by the sensor 1. However, the system can function without exciter 34 using only ambient electromagnetic fields and appropriate setting of the sensor frequency, but the recognisable separation distance will be smaller.

In addition contact detection can make use of the background electromagnetic noise. Structurally this simplifies to the loop 1-2-7-8-9-10-11-12-13-16. For this reason the gain of the amplifier 2 may have a wide range such that the resulting signal is always above the supply reference.

The establishment of a definite tool/workpiece contact may be additionally verified by detecting current through it from generator 33.

The frequency generator 4 simulates the tool/probe's operation to serve as a self-test function. The frequency of pulses generated at 4 must be higher of course then the number of pulses n that characterizes noise.

An advantage of employing the cutting tool itself as the measuring probe is that the system may also be employed to recognise tool wear. This recognition is achieved by emf alternative variable analysis. In the course of the machining process the cutting process itself generates an emf in the workpiece, spindle, machine frame, cutting tool loop which may be detected by sensor 1. The sensor output signal is sufficiently high to reach the contact detection channel - since of course the tool and workpiece by definition are in contact - and a cutting tool wear signal is output to the CNC machine. Breakage of the cutting tool will be recognised by any sudden short loop disconnection and disappearance of output to the CNC machine.

In this embodiment the tool itself acts as the measurement probe and this is advantageous in that when it is desired to make a measurement there is no need to bring a separate measurement probe into operation. However, a completely separate

includes means for controlling the speed of movement of said probe, and wherein said probe is caused to move toward said object at a slower speed upon an output from said first channel detecting the approach of said probe to said object.

9. Apparatus as claimed in any preceding claim further including means for confirming contact between said probe and said object by detecting flow of current between said probe and said object.

10. Apparatus as claimed in any preceding claim wherein said probe comprises the tool of a machine tool.

11. Apparatus as claimed in claim 10 wherein means are provided for determining the condition of said tool.

12. Apparatus as claimed in claim 11 wherein said means comprises means for monitoring the output signal of said sensor while said machine tool is in operation.

13. Apparatus as claimed in any of claims 10 to 12 wherein said sensor is provided around said tool.

14. Apparatus as claimed in any of claims 10 to 12 wherein said sensor is provided around a spindle on which a workpiece may be mounted.

15. Apparatus as claimed in any of claims 10 to 12 wherein said sensor is provided surrounding a set up attachment.

16. A precision measurement apparatus substantially as hereinbefore described with reference to the accompanying drawings.

17. A method for measuring the position of a point on the surface of an object made of electro-conductive material comprising, moving a measurement probe towards an object to be meaured, and detecting the position of the probe at which a

magnetic circuit is formed when the probe is in contact with or closely adjacent to said object.

18. A method for measuring the position of a point on the surface of an object substantially as hereinbefore described with reference to the accompanying drawings.

The Patent Office

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Claims searched: 1 to 18

Examiner: Mr A Oldershaw
Date of search: 4 March 1997

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): G1N NADP, NCTA, NCTB, NCTC, NCTD, NCTE; B3B BCB21, BCB25

Int Cl (Ed.6): G01B; B23Q

Other: Online: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB2241063A	(ROLLS-ROYCE)	1,17 at least
X	GB2064135A	(SCHMALL)	"
X	GB1504049	(WESTINGHOUSE)	"
X	GB1279411	(MASSEY-FERGUSON-PERKINS)	"

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
&	Member of the same patent family		